EXPERIMENTS WITH HIGH EXPLOSIVES IN LARGE GUNS.

BY HIRAM STEVENS MAXIM.

FOR many hundreds of years common black powder was the only explosive used in warfare, and it was not until after Nobel invented a process for the manufacture of nitro-glycerine, that engineers began to speculate upon the possibilities of using something stronger than common black powder for charging shells thrown from large guns.

The properties of nitro-glycerine were for many years but imperfectly understood. It was said of it that if you wished it to explode it was impossible to make it do so; if you handled it with great care and did not wish it to explode it was almost sure to go off; sometimes it could be set on fire, and would burn very much like a slow fuse, while again the least jar would cause the most frightful detonation. Evidently such an agent was not suitable for use in firearms, and it was only after Nobel's discovery that nitro-glycerine could be gelatinized with collodion cotton (di-nitro-cellulose) that engineers began to experiment with a view of using this high explosive in projectiles.

The naval and military engineers at Shoeburyness were among the first to conduct experiments, and it was found that when sufficient collodion cotton was employed to make the compound about the consistency of soft rubber, it could be fired with a comparative degree of safety from ordinary guns, providing, of course, that the powder charge used as a propellant was not too violent. Large numbers of rounds were fired under apparently identical conditions, with the result that perhaps 99 per cent. passed harmlessly out of the gun, while about 1 per cent. exploded in the bore of the gun, completely demolishing it.

Simultaneously with these experiments, Sir Frederick Abel was experimenting with compressed wet gun cotton, and he found that this explosive (tri-nitro-cellulose) when ground into a pulp, similar to paper pulp, and compressed while wet into slabs or blocks, could not be detonated by any ordinary means; that it could even be thrown into a white hot furnace with safety; but that it would detonate exactly like a fulminating cap, providing that a very large detonating charge of fulminate of mercury was employed, and this led to its universal adoption, not for use in large guns, but as the explosive charge in submarine locomotive torpedoes. However, it never has been used to charge projectiles fired from guns, except experimentally and on a small scale.

In 1884 I was consulted by a high Government official who told me that he had a quantity of German brown cocoa powder; he said that this powder produced remarkable velocities with phenomenally low pressures; it was a slow burning powder *par excellence.* He said that it was the easiest thing in the world to analyze it; he had given it to the leading chemists and scientific men to analyze, and they all agreed exactly as to the amount of carbon, sulphur and nitrate of potash present, but he added "when we make a powder here with the greatest care, containing the exact proportions that we find in this German powder, the results are totally different. Instead of high velocities and low pressures we get high pressures and low velocities, and still there is chemically no difference. There is nothing new in the chemicals employed, still we are asked to pay a very large sum of money for the secret. I have thought that perhaps you could put us on the right track and save the money. Can you tell us how the powder is made ?" I replied: "You have already told me yourself, but I will come to-morrow and tell it back to you again."

When he assured me that the powder was chemically the same as the powder made by the Government, I knew that the difference must be some physical condition due to the mechanical mixing of the material, and it occurred to me that in all probability the sulphur and charcoal were very finely ground and intimately mixed, and that the oxygen bearing salt (nitrate of potash) must have an appreciable size.

In nitro-glycerine the nitrogen groups carrying the oxygen and the combustible material are almost in chemical combination; that is, the ultimate atoms are almost in actual contact; the dis-

tance between the centre of the store of oxygen and the centre of the material to be consumed is infinitesimally small, perhaps not more than one thousand millionth part of an inch; but in ordinary gunpowder, although ground extremely fine, the distance between any particular particle carrying oxygen and the material to be consumed is enormously great as compared with the distance in nitro-glycerine. Now, if we wish to make the powder still slower burning, we shall only have to increase this distance. So thoroughly was I convinced that this must be true that I at once went to an instrument maker and bought a micrometer to use with my microscope. I took two prisms of powder, one made by the Government and the other German prismatic; I polished the surfaces and examined them. The Government powder appeared perfectly homogeneous, the particles were so finely ground, so intimately combined and so firmly pressed together that it appeared to be all one body. I then tried the German prismatic, and it appeared under the microscope, exactly like what is known as brawn or hogshead cheese; the sulphur and carbon were finely ground, but the nitrate of potash had a granular appearance, the largest grains being 1-200th part of an inch in diameter.

The next day I took my instrument and the powder and showed it to the official. He congratulated me very highly and said I had done them a good service. However, about a year later, he informed me that the eminent scientist employed in the first instance, never would forgive me for what I had done with my microscope. The discovery, however, led me to further investigation. I went to a powder mill, and made a batch of powder; I carefully weighed the charcoal and carbon, and ground them together under an edge mill, quite as fine as they would have been ground in the ordinary way. I then added the proper amount of nitrate of potash in a granular form, thoroughly mixed it, and when it had been under the action of the edge mill for about five minutes, I removed a few pounds. This I repeated at short intervals for about four hours. Upon trying these specimens, it was shown that powder could be made slow burning to any required degree; that there was a constant change in the powder in the mill for about one hour, after which time very little change took place, that which was ground four hours being only slightly more violent in its action than that which was ground for two hours; while there was a great difference between that which had

been in five minutes and that which had been in twenty minutes. Some of these powders were afterward granulated, others compressed into cubes and tried before Government officials, when my theory in regard to slow burning powder was fully borne out.

Having found that powder could be made slow burning, I next arranged it in such a manner as to be progressive—that is, I pressed the powder into blocks and cubes, and loaded cartridges in such a manner that the first powder to be burned would be slow burning, and the last to be burned quick burning, so that as the projectile moved forward in the barrel, the powder would burn faster and faster, thus maintaining the pressure and imparting to the projectile a high velocity without a high initial pressure. It was also found that the violence of the shock was much lessened by the use of progressive powder.

I then determined to construct a gun for throwing high explosives, such as nitro-gelatine and compressed gun cotton, from a powder gun. At that time, considerable discussion was taking place in regard to the utility of submarine torpedoes. Mr. Bryce-Douglas, who was then Chief Engineer of the Fairfield Shipbuilding Works, Glasgow, expressed it as his opinion that it would be almost impossible when ships were in motion to discharge a torpedo in such a manner as to hit another vessel except at very short ranges. He said that the eddying and whirling of the water would be such as to make torpedoes almost as dangerous to the ship throwing them as to the ship aimed at. At that time torpedoes were projected into the water by compressed air, or by a small powder charge, throwing them perhaps forty feet from the ship. Why not make this tube larger and throw the torpedo through the air to the ship instead of throwing it in the water? This would make the torpedo much cheaper, there would be greater certainty of hitting and the effective range would be greatly increased. Acting upon these suggestions I constructed a torpedo gun, using progressive powder arranged in such a manner as to start the torpedo on its flight at a relatively gentle pressure and increasing the pressure on the projectile as the torpedo moved forward in the bore. I also provided my torpedo with a peculiar fuse, the striker being a long distance from the fulminating cap, so as to give a delayed action, permitting the projectile to enter the side of a ship, or to sink a certain distance in the water before exploding. It was found in these experiments that almost any

velocity could be imparted to the projectile with very little shock, the powder being completely under control.

I then found that there was great prejudice against the use of high explosives on board ship. I also found that the prejudice was so strong against throwing high explosives by the use of any sort of gunpowder as to make it absolutely impossible to get the apparatus tried anywhere. In the meantime, I had found the cause of the supposed mysterious explosion which occurred when nitro-gelatine was used at Shoeburyness. If a projectile was loaded in such a manner that a considerable quantity of air was imprisoned between the base of the projectile and the nitro-gelatine, it would be very violently compressed when the shot was discharged, and the heat developed would sometimes cause an explosion. I found that if the air was completely removed, so that not even a bubble was present, this source of danger was removed, and I made an apparatus for removing air bubbles from nitro-gelatine, and loading the mass in the projectile in such a manner that no air was present. I knew at that time that no explosives would detonate or explode in a vacuum.

Another source of danger, especially when compressed gun cotton is employed in rifled cannon, arises from the quick and violent twist given to the projectile, which rotates the case or shell, without rotating the bursting charge. This I obviated by dividing the interior of the shell into numerous compartments. Still no one could be persuaded to use my torpedo gun.

In the meantime, the French had been experimenting with picric acid, under the name of milenite, with fairly good results.

The next step was the Zalinski gun. This had been made and tested in the United States, when it was found that large charges of high explosives could be thrown considerable distances from an air gun. One of these guns was brought to England and fired at Shoeburyness. It was said at the time that three shots fired with the gun firmly locked in a stationary position landed in the same hole in the mud. The accuracy was admitted to be remarkable, but the velocities were so low, the range so short, and the trajectory so high, that it was almost impossible to hit the target when the gun was fired from a ship. It was even said that if the gun were properly aimed from a ship and the trigger pulled, the barrel, on account of its great length, would move sufficiently after the trigger was pulled and before the shot left the

gun, to throw the shot completely off the target. Still, it was believed that under certain conditions the gun might be useful for fortifications. In any compressed air gun of the Zalinski type, it will be evident that an increase in the atmospheric pressure is not attended by a corresponding increase in the velocity of the projectile, because the higher the pressure of the air the greater its weight and density, so that when the pressures are increased, we will say from 2,000 to 3,000 lbs. per square inch, the actual velocity of the projectile is only slightly increased. It occurred to me at that time that if the pressure could be increased without increasing the weight or density of the air a great improvement would result. I therefore constructed a gun in which I used only 1,000-lbs. pressure per square inch. The gun was arranged in such a manner that when the air passed from the reservoir into the chamber of the gun it took along with it a small quantity of gasoline, just enough to render the mixture explosive, the same as the mixture in a gas engine. The gun being loaded, in order to fire the trigger was pulled, which acted upon a large balance valve, which suddenly sprang open; the projectile was then driven forward in the bore with a pressure of only 1,000 lbs. per square inch. When the projectile had moved from 2 to 3 calibres, the charge of gasoline and air was ignited, and while the projectile was still moving forward, the fire ran back into the chamber, constantly raising the pressure, so that by the time the projectile had reached the muzzle of the gun the pressure had mounted from 1,000 to 6,000 lbs. per square inch, and the result was a comparatively high velocity with a short barrel. This gun was fired a great number of rounds in 1888, and found to be quite reliable. A peculiar feature was that the report of this gun was very loud and violent, showing that the final pressure was very high, while in the Zalinski gun the report is very feeble, showing that the final pressure is low. But this gun never went beyond the experimental stage. All the naval men with whom I came in contact were opposed to having any kind of high explosive on board ship, many of them even objecting to compressed gun cotton used in torpedoes, while not a few did not believe that torpedoes would be of much value in a sea fight.

In the meantime a long series of experiments had been made at Portsmouth on H. M. S. "Resistance." The name seemed to have been well chosen. This old ship was torpedoed time and

again, patched up and made as good as new. The experiments demonstrated that the ordinary submarine torpedo was nothing like as destructive as one had been led to believe. Experiments were also made with lyddite (which is the English name for milenite) with projectiles loàded with various high explosives. Then black powder was tried, and I remember distinctly that it was said that, everything considered, old-fashioned black powder answered the purpose best; it appeared to be quite as destructive as any other agents employed, was more apt to set the ship on fire, and produced an immense amount of smoke, which was demoralizing to the men and enabled the gunners to see where their shots had struck better than any other form of powder.

The "Resistance" experiments were very discouraging to me at the time, and my aërial torpedo experiments were practically abandoned—especially so as I had learned from experiments made at Annapolis that compressed gun cotton, dynamite, nitro-gelatine and so forth, had little or no effect upon armor plates.

It was then that I commenced my experiments in smokeless powder. It was known that the French had a smokeless powder, and every one in England was anxious to find out what this powder was. I had witnessed the firing of many rounds from Maxim guns in France, and from the smell of the fumes while firing it occurred to me that the powder employed might be a gun cotton compound. It was gun cotton dissolved in a solvent, made into sheets, dried and granulated.

The first smokeless powder that I made in England was made in exactly the same manner as the French. I had obtained a quantity of true gun cotton, that is tri-nitro-cellulose (known sometimes as insoluble gun cotton because it cannot be dissolved in alcohol and ether like collodion cotton, di-nitro-cellulose). Some of this powder, when freshly made, produced fairly good results, quite as good as those produced by the French powder, but upon keeping it for a few months the grains lost their transparency, became quite opaque and fibrous, and it then burned with great violence. Investigation showed that about 1 to 2 per cent. of the solvent was still in the powder when the first tests were made, whereas the drying out of this last trace of solvent had completely changed the character of the powder. I then added to this powder about 2 per cent. of castor oil, with the result that the castor oil remained after the solvent had been completely removed,

so that the powder would keep any length of time—indeed powder made at that time (1889) is quite good to-day.

But I wished to produce still higher results. I knew nothing of what other experimenters were doing, but it occurred to me that it would be very curious if two violent explosives like nitro-glycerine and gun cotton could have the same amplitude of molecular waves passing through them when the explosion took place. It also occurred to me that if the two substances were intimately combined, made into a liquid and mixed together and then dried, it might be found impossible for a molecular wave to pass through both of them. For instance, if we should take a plate of ice two inches thick and put it in a glass box four inches thick, the light would pass through both the ice and the two inches of air space, but if we ground the ice very fine, so that it filled the whole space, *i. e.*, the ice and air being thoroughly mixed together as in light snow, a wave of light would not pass through the two; in fact, the mixture would completely shut out the light, giving a black shadow. I believed that if the nitro-glycerine and the gun cotton were intimately combined an explosive wave would not pass through the mixture, and experiments revealed that I was quite correct. All mixtures of from 1 per cent. to 75 per cent. of nitro-glycerine were experimented with, the result being that from 10 to 15 per cent. was found to be the best, everything considered. If larger percentages of nitro-glycerine were employed, there was little liability of detonating when new, but it was found that the nitro-glycerine would gradually ooze out, or one might say evaporate out and condense in the cartridge case, forming pools, and a very little free nitro-glycerine was quite sufficient to set off the whole of the charge.

The experiments also demonstrated that when pressures not exceeding 15 tons were employed, almost any degree of slow burning could be obtained with these smokeless powders, and this again led to the suggestion that they might advantageously be employed in throwing aerial torpedoes from large guns.

The greater part of the smokeless powders employed to-day consist of a mixture of nitro-glycerine and gun cotton. The mixing is brought about by the agency of acetone, a species of alcohol which dissolves both gun cotton and nitro-glycerine. When a small quantity of this spirit is present the mass is of a semi-plastic consistency and may be squirted or spun through a

die by pressure, in the same way that lead pipe is made. The first powder experimented with was drawn into threads and called by the British Government "cordite." This was found to work admirably in small-bore ammunition, but when it came to a question of larger guns it was found advantageous to form the powder into tubes with one or more holes. It will be readily understood that when the powder was drawn into long, cylindrical threads the burning surface, and consequently the evolution of gas, would constantly diminish as the threads burned thinner. When, however, the powder was made tubular, the burning from the inside and outside being equal, the burning surface remained practically constant and produced much better results in the larger type of guns than it was possible to produce with the solid threads or sticks of powder. By increasing the number of perforations, it was found that a powder could be made which, instead of burning slower and slower as the projectile moved forward in the gun, would cause the development of gas to increase as the projectile moved forward with accelerated velocity in the bore. This was exactly what was required, and led to my patent on progressive smokeless powder—that is, the powder in which the burning surface increases while it is being consumed, instead of diminishing, and it was thought that this might be advantageously employed instead of compressed air for throwing torpedoes or high explosives.

At that time it was generally understood that modern smokeless powders were inherently slow burning, and experiments of Sir Andrew Noble seemed to point in this direction. Still it was believed by many that it would not be safe to throw any high explosive from a gun using a similar explosive as a propellant, for fear of the charge being detonated by what is known as sympathetic action.

In order to settle the question as to whether cordite would burn slowly in large quantities or would detonate, the British Government made a very interesting but disastrous experiment at Plumstead. A large quantity (a ton or so) of smokeless powder was set on fire. It flared up for a few seconds, and then detonated exactly like dynamite, excavating a hole in the earth about 15 feet in depth and 20 feet in diameter, and breaking a great deal of glass within a radius of a mile. This seemed to prove that when this kind of powder was ignited in large quan-

tities the rapidity of burning went on in geometrical progression, commencing slow at first, then as the pressure of the gas increased the heat, the heat increased the rapidity of burning, the rapidity of burning again increasing the pressure of the gases on the burning surface, which again re-acted upon the heat—thus action and reaction taking place in rapid succession. The rapidity of burning very soon approached to the point known as detonation. Others claim that the powder detonated on account of the presence of a considerable quantity of free nitro-glycerine which had been evaporated and condensed or had oozed out of the surface of the powder, it being remembered that the British Government powder contains 58 per cent. of nitro-glycerine.

Wishing to arrive at the exact truth in this important and interesting problem, I procured a considerable quantity of various grades of smokeless powder, the surface of all of them being quite free from exuded nitro-glycerine. I filled two large steel cylinders with this powder, placed them in close proximity to each other, and inserted a fuse with a very large detonating cap in cylinder No. 1. When the fuse was fired, both the cylinders detonated exactly like so much dynamite, making a deep excavation in the earth. Had I used only a small fulminating cap, the first steel cylinder would have exploded before half the powder had been consumed, and a large quantity would have been found unconsumed in the immediate vicinity, while the second cylinder would not have exploded at all. These experiments went to show that all forms of modern smokeless powder can be detonated, providing that the fulminating charge that sets them off is sufficiently large and powerful.

In one lot of foreign made rifle ammunition we had four cartridges out of a lot of 40,000 detonate and destroy Maxim guns. This was probably due to carelessness in putting two charges of fulminating powder in the primer instead of one.

Nitro-glycerine is slightly volatile--that is, air coming in contact with nitro-glycerine will take up a very small quantity of it, and it has been found that where English cordite with its large percentage of nitro-glycerine is being dried (that is, deprived of its acetone), all the surrounding objects in time become coated with pure nitro-glycerine. This led me to believe that under favorable conditions the nitro-glycerine of the cordite might be

transferred from the cordite to the metallic case of the cartridge. I therefore constructed a cylinder in which I placed about ten pounds of cordite. This cylinder was provided with a water jacket and heated by gas, the flame being regulated by a thermostatic regulator which kept the temperature constant at 100 degrees F. A similar but smaller cylinder was connected to this top and bottom, but instead of being heated, it was cooled by a circulation of water. By this arrangement, when the apparatus was hermetically closed, there was a constant interchange of air, the air passing up through the heated cylinder containing the cordite, and down through the cooler cylinder. At the end of one week, pure nitro-glycerine commenced to run out into the bottle attached to the lower end of the cold cylinder, and this continued for several weeks until a considerable quantity was obtained. Upon making the same experiment with cordite containing only 10 per cent. of nitro-glycerine, only a few drops of water which proved to be quite free from nitro-glycerine were obtained. As it only requires a very small quantity of free nitro-glycerine to make a cartridge detonate instead of exploding in the ordinary way, it is believed by some that when large cartridges loaded with cordite are kept for a considerable time in varying temperatures, they will become dangerous on account of the free nitro-glycerine, which may collect in the cases or be condensed as a dew over the whole of the interior of the metallic cases. In the olden time when guns were not rifled, and spherical shots were employed with a powder charge of about one-eighth of the weight of the projectile, the erosion caused by the gases passing the projectile was so small as to be considered a negligible quantity—in fact, its existence was practically unknown to the majority of artillerists at that time, but upon the introduction of rifled guns with elongated projectiles and heavy powder charges erosion became a serious obstacle, which increased as the power and range of the gun increased. Large guns made in England from 10 to 15 years ago, using black or cocoa powder with projectiles of 3 or 4 calibres, and having a velocity rather less than 2,000 feet per second, were destroyed after firing from 300 to 400 rounds. When the velocities were increased to about 2,200 feet it was found that the wear was about four times as great, while some very powerful guns made in France were completely worn out after firing 60 rounds. With smokeless powder, which gives a still higher velocity to the pro-

jectile, the erosion is still further increased, so that in some cases I have known guns to be destroyed after firing only a few rounds.

The next step was to prevent this cutting away of the steel from the inside of the gun by the action of the white-hot gases moving at a terrific velocity past the projectile. Various kinds of copper driving bands have been experimented with. These driving bands consist of a copper ring let into the projectile near its base, the periphery of the ring being of a sufficient diameter when pressed forward into the rifling to form a gas-tight joint between the projectile and the rifling, and at the same time give the necessary rotatory motion to the projectile. It will be understood that the copper band is the only part of the projectile which enters the grooves, or, as is said, "takes the rifling." These bands work very well while the barrel is quite new, but as soon as a small quantity of gas passes, the steel becomes very rough, so that the copper bands are cut away by the rough steel, while the passing gases from each successive shot make the steel still rougher, sometimes scooping out holes as big as a filbert after only a few rounds have been fired.

In order to obviate this trouble we have provided the projectiles with what might be termed an obturating band; that is, just behind the copper driving band we have placed a semi-plastic gas check. Behind it is placed what might be termed a junk ring, arranged in such a manner that when the gun is fired the junk ring moves forward and subjects the gas ring to a pressure 20 per cent. greater than the pressure in the gun—that is, if the pressure in the gun amounts to 14 tons per square inch the pressure on the gas ring is about 17 tons to the square inch. This is found to completely stop the passage of gas between the projectile and the bore of the gun; so we are now able to fire large guns many hundreds of rounds with full charges before any perceptible wear takes place in the barrel. This will enable our naval authorities to practice gunnery to almost any extent without the danger of wearing their guns out, and it is believed by many that in the near future no large guns will be fired on shipboard without the employment of the obturating gas check.

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